Real-time Early Warning Techniques

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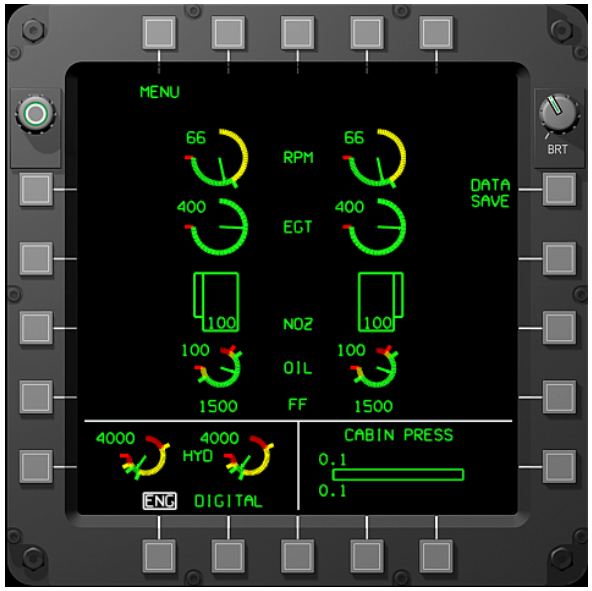
Contemporary System Health Management

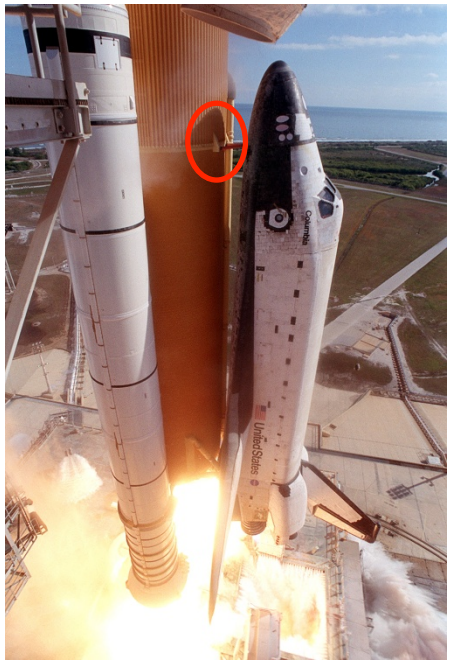


- Contemporary system health management
  - High reliance on thresholds
  - Compromise between early warning and false alarms
  - "One-sensor, one-indicator" paradigm
  - Automation often reduces info displayed to the operator

- Improve aerospace vehicle safety by monitoring for anomalous patterns of behavior

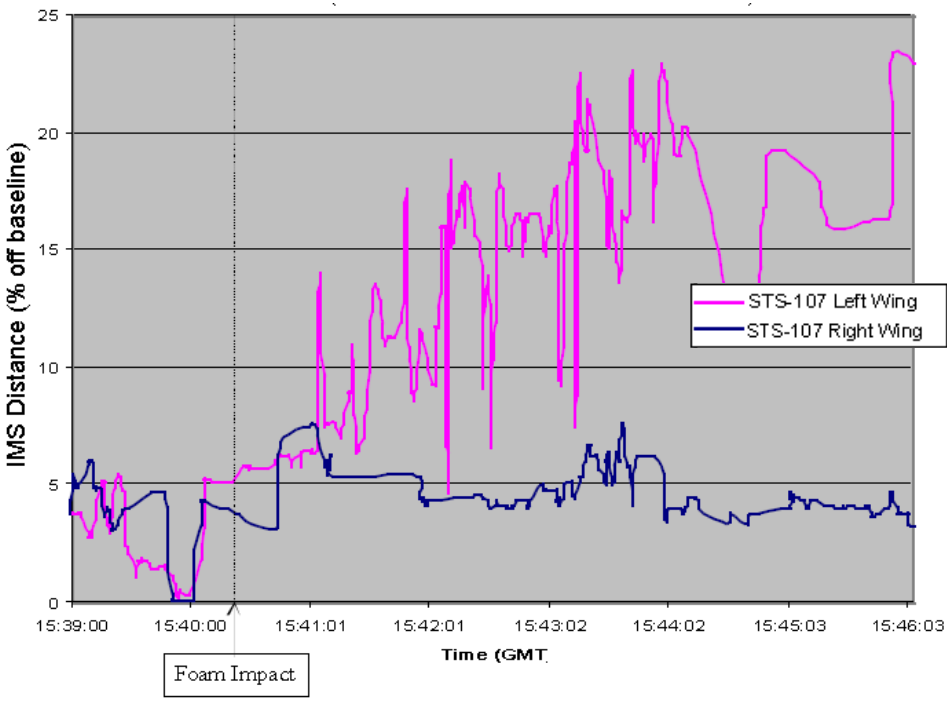
Example 1: Columbia Disaster

- Columbia summary
  - Space shuttle mission STS-107 catastrophic breakup on reentry (1 Feb 03)
  - Caused by foam impact to left wing leading edge 82 seconds into ascent which compromised thermal protection
- Retrospective Temperature Sensor Analysis
  - Left wing temperatures were within limits
  - Anomalous left wing temperatures
    - Compared to right wing
    - Compared to prior flights
  - Temperature data could have been used to raise alarm earlier
  - Served as an early test case of the Inductive Monitoring System (IMS)



Inductive Monitoring System (IMS)

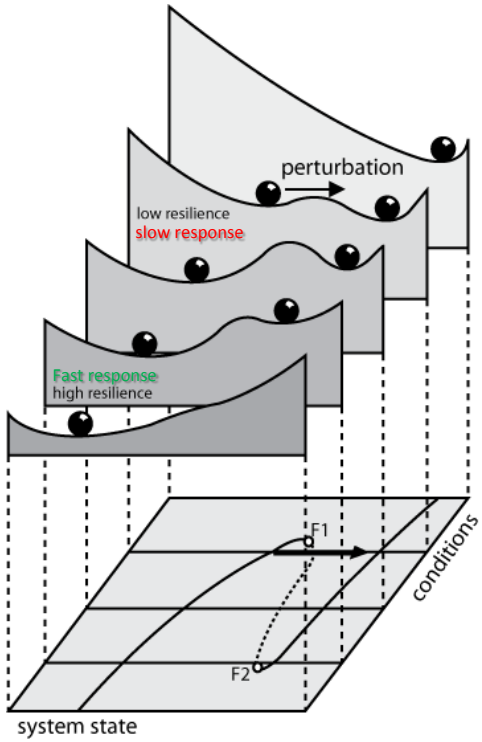
- Early warning option for systems with an established baseline
- IMS algorithm specifics
  - Compares real-time data to nominal archived data
  - Employs a hybrid of two clustering techniques
    - K-means clustering
    - Density-based spatial clustering
    - Creates a vector of parameter values for comparisons
  - Indicates how far system behavior is from nominal
  - Useful for composite, or interrelated, parameters



- Composite parameters
  - More sensitive to deviation from expected values
  - Can indicate an anomaly before manifestation in individual parameters
- In the Columbia Example, IMS would have indicated anomalies on ascent instead of just on reentry (17 days later)

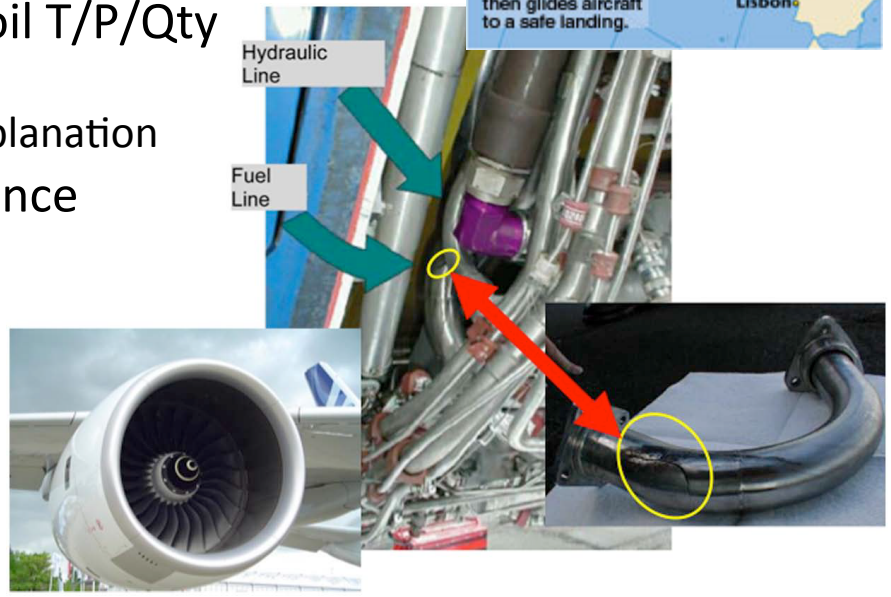
Critical Slowing Down

- Early Warning option for systems without an established baseline
- Goal: Predict transition between contrasting dynamical regimes
- Method: Exploit indications of critical slowing down
  - Increasing auto-correlation
  - Slower recovery from perturbations
  - Increasing variance (conditional heteroscedasticity)
  - Fluctuation asymmetries (skewness/kurtosis/flickering)
- Demonstrated: ferromagnets, siezures, etc.
- Handling Qualities, Stability, Flutter, etc.

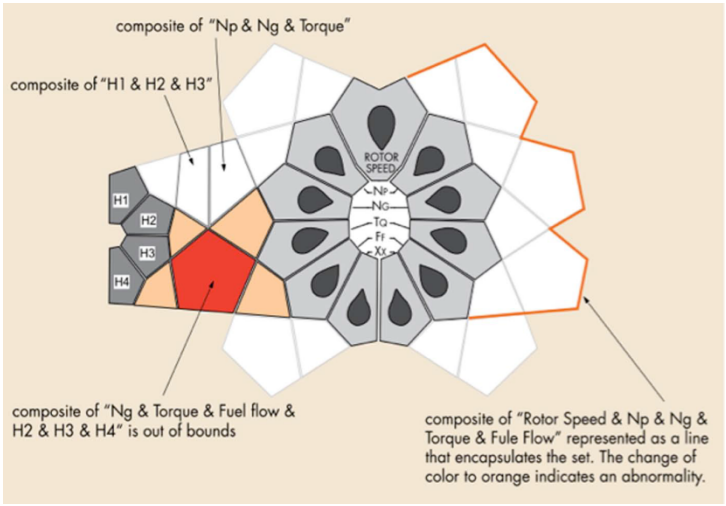


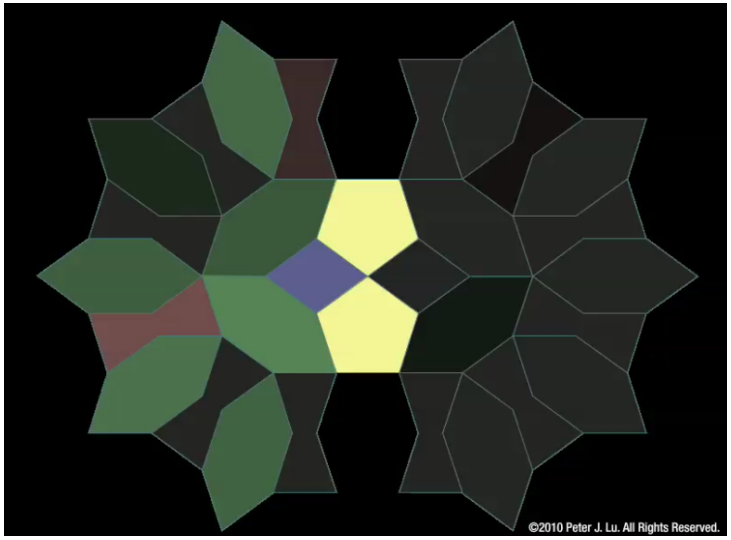
Example 2: Air Transat Flight 236

- Flameout Landing in the Azores on August 24, 2001
  - Airbus A330-200, 306 passengers/crew
  - Original flight plan: Toronto, Canada to Lisbon, Portugal
- Mishap timeline in UTC
  - 04:38 (3+46 into the flight) Right engine fuel leak began
    - High pressure line ruptured into a 3.5 x 1/8 inch crack
    - Resulted in a 60 gallons/min fuel flow overboard
  - 05:03 Aircrew observed abnormal oil T/P/Qty
    - All still within limits
    - Conference hotel did not offer an explanation
  - 05:33 Aircrew observed fuel imbalance
    - Crossfed IAW checklist
    - Made the situation worse
  - 05:45 Initiated divert to Lajes
  - 06:13 Right engine flamed out
  - 06:26 Left engine flamed out
  - 06:45 Safe landing at Lajes Air Base
- No indications the oil anomalies and fuel imbalance were related



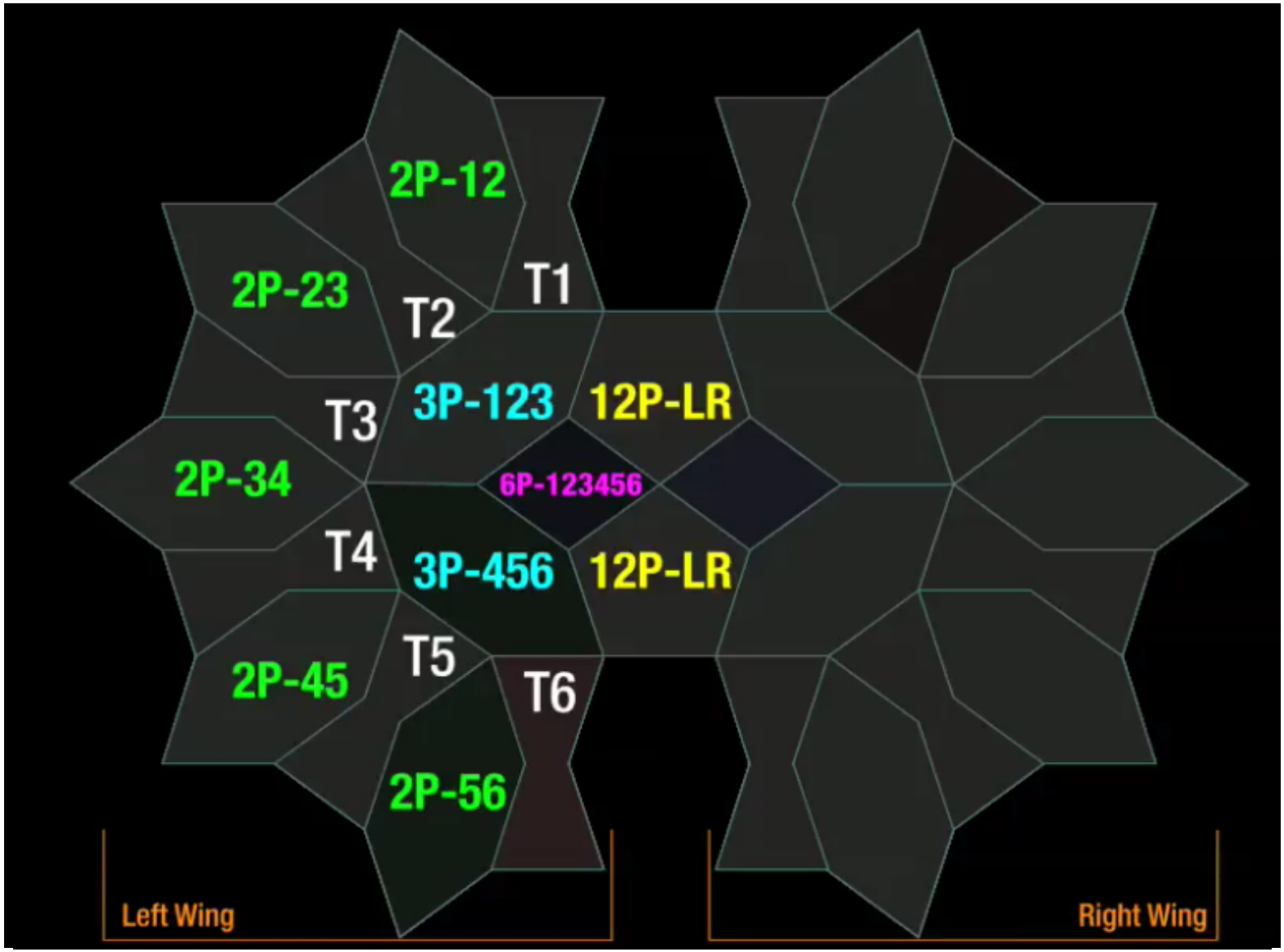
Composite Parameter Display





- With more automation
  - More information is needed, not less
  - Flight 236 automatic trim tank transfers dumped additional 3.5 tons
  - Presentation matters
  - More dials is not the answer
- Aircraft systems are not federated but the displays are
- Challenge the current "one-sensor, one-indicator" paradigm
- Display that geometrically represent s interrelationships
- UH-60 and Columbia examples

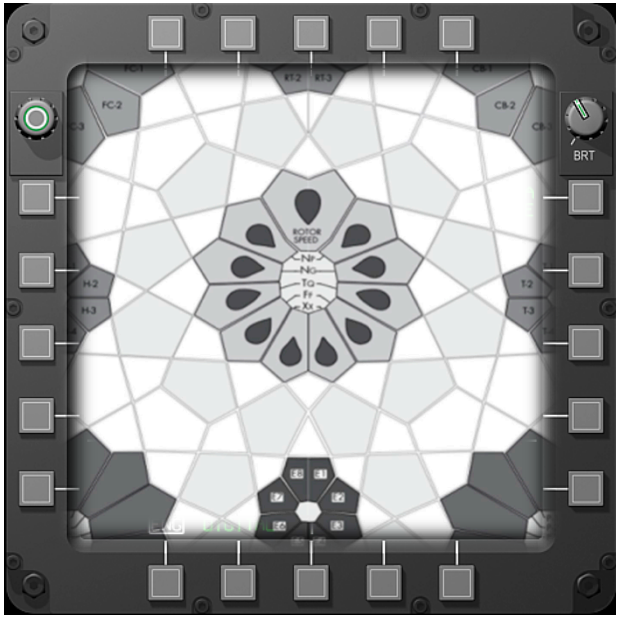
Sample Columbia Display



Bottom Line

- Aerospace vehicle system health management can be improved by:
  - Introducing methods beyond threshold exceedance
  - Monitoring for anomalous patterns of interaction to provide earlier warning
  - Monitoring for composite parameters to capitalize on interrelationships
  - Developing displays that represent the true complexity of aircraft subsystems

- Continuing work
  - Test Pilot School Test Management Project
  - Incorporation into the USAF Academy Flight Test Course
  - Applying these techniques to other fields (Big Data, geology, social science, etc)



Questions?

Clustering Backup